COV ITRM Guideline 94-3

Commonwealth of Virginia

Information Technology
Resource Management
Guideline

Global Positioning Systems (GPS)

Council on Information Management

Preface

PUBLICATION DESIGNATION
COV ITRM Guideline 94-3.

SUBJECT:
Global Positioning Systems (GPS).

EFFECTIVE DATE
July 15, 1994.

SCHEDULED CIM REVIEW
One (1) year from effective date.

AUTHORITY
Code of Virginia, §2.1-563.31 (Powers and Duties of the Council on Information Management).

SCOPE
This Guideline is applicable to all State agencies, activities, and institutions of higher education (hereinafter collectively referred to as "State agencies") that are engaged in such functions as planning, managing, developing, purchasing, and using information technology resources in the Commonwealth.

PURPOSE
To ensure the effective integration of GPS technologies into the information and technology infrastructure of the Commonwealth.

To assist State agencies in evaluating the most effective and cost beneficial use of GPS technologies.

OBJECTIVE
This guideline will:

- Provide an overview of GPS and how it works;
- Provide an overview of potential GPS uses and how it is currently being used in State Agencies;
- Recommend adoption of appropriate GPS technical standards, guidelines, and specifications; and
- Provide technical direction for procuring and using global positioning systems and related technologies to support government operations.

GENERAL RESPONSIBILITIES
In accordance with the *Code of Virginia*, the following provisions apply:

The Council on Information Management (CIM)
Responsible for:

Directing the development and promulgation of policies, standards, and guidelines for managing information technology resources in the Commonwealth.

Advisory Committees
Responsible for:

Meeting, conferring with, and advising the Council in the development of the Commonwealth's technical advisories, policies, standards, and guidelines for managing information technology resources.

The Department of Information Technology (DIT)
Responsible for:

Providing administrative support to the Council and performing such other services as the Council may direct in the performance of its powers and duties.

All State Agencies
Responsible for:

Cooperating with the Council in the performance of its powers and duties; and

Complying with the Council’s policies, standards, and guidelines for managing information technology resources in the Commonwealth.

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GLOBAL POSITIONING SYSTEMS (GPS)

INTRODUCTION

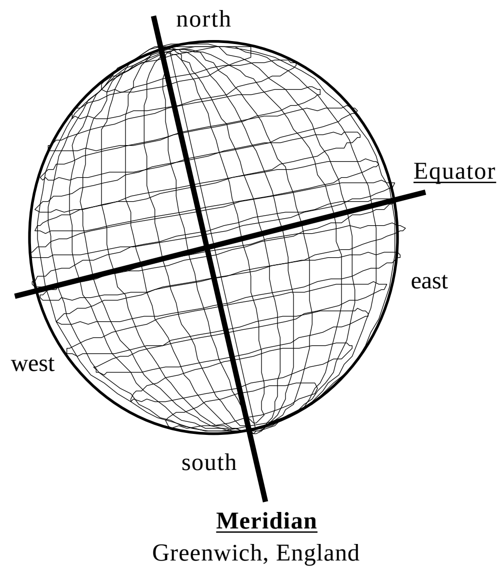
Throughout time, we have always had the need to define where people, places and things can be located on the face of the earth. We have progressed from crudely marking paths and trails to developing detailed maps and using sophisticated electronics. Today, using global positioning systems (GPS) capabilities, we can accurately determine the location (latitude, longitude and altitude) of people, places and things almost instantaneously. In addition, GPS can determine direction and calculate velocity based on multiple rapid location determinations.

Figure 1 - Positioning

Latitude - the angular distance in degrees, minutes and seconds of a location north or south of the equator. Position is described by the intersection of longitude and latitude.

Longitude - the angular distance in degrees, minutes and seconds of a location east or west of a meridian which runs through Greenwich, England.

Altitude - the distance between sea level and a point on or above the earth's surface.



Source: GPS Government's New Utility, GT Publishing Inc., 1992

DEFINITIONS AND CONCEPTS

While the technology behind GPS is incredibly complex -- it includes orbiting satellites, atomic clocks, computers and transmitters -- the business end of GPS is small enough to fit into a hand-held package. GPS is easy to use, is relatively inexpensive ($500 - $150,000) and is revolutionizing navigation, surveying, mapping, dispatching and a wide range of location-dependent activities. However, GPS has various error factors that must be overcome and also has several limitations that restrict its use. Limitations include: requires line-of-sight with the satellites it is tracking; buildings, trees and other structures can obstruct the radio signals; and it won't work underground or underwater.

This capability to determine location, direction, and velocity has been provided compliments of the United States Department of Defense (DOD) via the NAVSTAR global positioning system (GPS). GPS can be defined as: *a constellation of earth-orbiting satellites transmitting precise time and location information on a continual basis that can be picked up by receivers and used to determine location.*

Figure 2 - GPS Satellites

Name: NAVSTAR

Altitude: 10,900 nautical miles

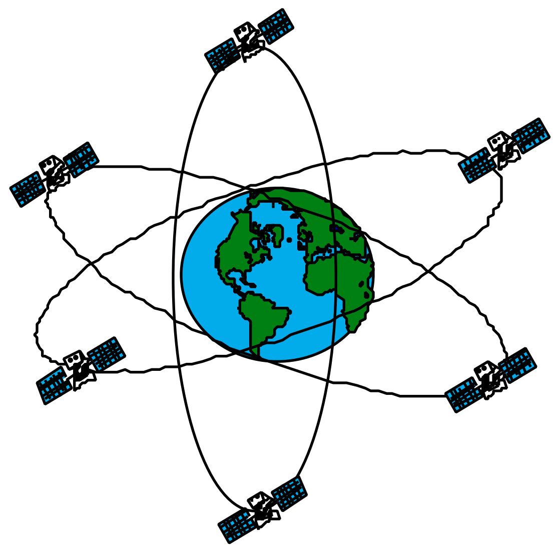
Weight: 1900 lbs

Size: 17 ft with solar panels extended

Orbital Period: 12 hours

Orbital Plane: 55° to equatorial plane

Constellation: 24 satellites



Source: GPS A Guide to the Next Utility, Trimble Navigation

GPS consists of three segments: space, control and user. The space segment contains the satellites orbiting the earth transmitting radio signals to users worldwide. A ground control network tracks the satellites, determines orbits precisely, and transmits orbit definition and correction information to each satellite. GPS users receive and process the radio signals to determine position at a point in time, and calculate direction and velocity based on multiple location determinations.

HOW GPS WORKS

GPS is based on our ability to measure the distance from multiple known points in space to the specific position of a receiver and use geometry to determine its location. The NAVSTAR constellation satellites serve as the known points in space and the process of determining distance from one of these satellites is commonly known as "***satellite ranging***".

The GPS system works on the old "***velocity x travel-time = distance***" equation. It measures how long it takes a radio signal traveling at approximately the speed of light to reach a receiver from a satellite, then calculates distance based on that time. The designers of GPS came up with the clever idea of synchronizing the satellite and receiver clocks so they generate the same code at the same time. To determine the radio signal's travel time, the GPS receiver receives the codes from the satellite and looks back to see how long ago it generated the same code. The time difference is how long the signal took to travel from the satellite to the GPS receiver. Because the time of signal reception is extremely critical to determining the range from each satellite, a minimum of four satellites must be observed to determine location and handle potential clock errors.

Both the satellites and the receivers generate a complicated set of two types of digital codes. The codes are made complicated on purpose so that they can be compared easily and unambiguously. The codes are so complicated they almost look like a long string of random pulses. However, they are not random, they are carefully chosen sequences, one repeats every millisecond and the other every 267 days. For this reason, they are often referred to as the "***pseudo-random***" code.

Code phase measurement uses the pseudo-random code to achieve GPS receiver positions. For highly accurate positioning, carrier phase measurement techniques can be used. Carrier phase measurement uses the radio frequency on which the code is carried to achieve more precise results.

GPS ERROR FACTORS

There are many factors that introduce uncertainty and errors into GPS's ability to determine the distance from a satellite, and thus its ability to accurately determine location. These include the following error factors which are summarized in Figure 3:

- Clock errors which occur when the satellites and the GPS receivers are not generating their codes at exactly the same time.

- Ephemeris errors which are caused by minor variations in a satellite's orbit.

Figure 3 - GPS Accuracy

The accuracy of GPS can purposefully be degraded by the Department of Defense using an operational mode called "Selective Availability" or "SA". SA is designed to deny hostile forces the tactical advantage of GPS positioning. When, and if, it is implemented it will be the largest component of GPS error.

	Error Source (typical)
Satellite clock error	*2 feet*
Ephemeris error	*2 feet*
Receiver errors	*4 feet*
Atmospheric/ionospheric	*12 feet*
Worst case SA (if implemented)	*25 feet*
TOTAL (ROOT-SQUARE SUM)	*15 to 30 feet (depending on SA)*

To calculate the predicted accuracy, multiply the total above by the PDOP (Position Dilution of Precision). PDOPs under good conditions range from 4 to 6. So the position accuracy that you can expect would be:

Typical - good receiver	***60 - 100 feet***
Worst case	***200 feet***
If SA implemented	***350 feet***

The above horizontal accuracy values can now be achieved by using a stand alone GPS receiver. Technology and signal availability policies are still evolving; therefore, the future error source values will in all probability slightly modify obtainable accuracy.

Source: GPS A Guide to the Next Utility, Trimble Navigation

- Errors caused by the radio signal slowing down, then speeding up as its passes through the earth's ionosphere.

- Errors caused by the radio signal slowing down, then speeding up as its passes through weather systems (water vapor) in the earth's atmosphere.

- Errors in GPS equipment/software such as: rounding off in mathematical operations or electrical interference that cause an erroneous correlation of the pseudo-random codes.

- Positional Dilution of Precision (PDOP) means that position determinations can be better or worse depending on which satellites are used to make the measurements. This doesn't mean that one satellite is better than another, but depending on a satellite's relative angle in the sky, it can magnify or lessen all the uncertainties mentioned above. In simple terms, the wider the angle between satellites the better the measurement.

- The Department of Defense controls this network of satellites. For reasons of National Security, signals can be turned off, weakened, and/or programmed to transmit erroneous data. These DOD tampering procedures are often referred to as anti-spoofing (AS) and selective availability (SA).

- Selective availability (SA) as implemented by the Department of Defense in 1991 is the largest component of GPS error. SA is essentially a DOD method for artificially creating a significant clock error in the satellites.

U.S. GOVERNMENT GPS SERVICES

U.S. Government policy defines two levels of GPS accuracy, a Precise Positioning Service (PPS - military) and a Standard Positioning Service (SPS - civil). The PPS consists of a navigation message transmitted at two frequencies in the L-band and provided through two digital codes, the Coarse/Acquisition Code (C/A Code) and the Precise Code (P-code). An encrypted form of the P-Code, called the Y-Code, is included in the PPS as are the factors necessary to correct for selective availability (SA) effects. The SPS consists of the navigation message and the C/A Code transmitted at the L1 frequency and is available free of direct charges to any user in the world.

The PPS is available to only the Department of Defense (DOD) and other authorized users and is denied to non authorized users through cryptography. Limited private sector civil use of PPS, both domestic and foreign, may be granted to users meeting certain criteria by applying to the Civil PPS Program Office that will be established by the U.S. Coast Guard.

The DOD is preparing a GPS-SPS signal specification which describes the signals and services to be made available for civil use. The SPS accuracy, established at a peacetime level of 100 meters, is created through implementation of SA which affects the basic parameters of the navigation message processed by user equipment. Although SA affects both the C/A-Code and the P-/Y-Code, PPS users overcome these errors through encrypted correction terms in the navigation message. By decision of the President, the SPS accuracy can be degraded beyond 100 meters, if necessary, for national security purposes. Such action would only be taken under dire circumstances, since SA actions affect all SPS users around the world.

GPS ERROR CORRECTION

The accuracies of the SPS and PPS do not satisfy the growing needs of many civil users of GPS. As a result, there has been a continuing investigation of methods to improve basic GPS accuracy and reliability, with differential correction being the most promising option currently available. Differential correction (usually referred to as "*differential GPS"* or "*DGPS*") is the process of collecting satellite data with a receiver placed on a known location (base station) and using the collected satellite data to determine the amount of error in the position calculation. Because of the simplicity of the GPS signal, this single correction factor, in effect, takes care of all the possible errors in the system, whether they're from receiver clocks, the satellite clocks, the satellite's position, or ionospheric and atmospheric delays. The amount of error calculated using DGPS can be used by other GPS receivers that are in the local area to correct their position solutions.

Virginia's high accuracy reference network (HARN) of 100+ geodetic monuments established by the National Geodetic Survey in cooperation with the Virginia Department of Transportation **will provide the most accurate known locations in Virginia for use with differential GPS**. These monuments were established at the FGCC B-order accuracy level.

FGCC Standards

The relative accuracy standards for geodetic control monuments are established by the Federal Geodetic Control Committee. They are defined as B-, A-, and AA-order geometric relative-accuracy at the 95 percent confidence level for GPS vector components:

B-order = 8 mm + 1:1,000,000 (or 1.0 mm/km)
A-order = 5 mm + 1:10,000,000 (or 0.1 mm/km)
AA-order = 3 mm + 1:100,000,000 (or 0.01 mm/km)

DGPS can be either real-time or post-processed. In a real-time mode, the base station calculates and broadcasts the error for each satellite as each measurement is received, allowing remote GPS users to correct their data immediately. This is useful when remote users need to know where they are at a given time. The base station can also log the measurements in a computer file so remote users can calculate the error and correct their data at a later time. This is usually referred to as post-processed and is useful when users need to know where they were at a given time. Real-time broadcast or logged differential correction information can be provided by permanently established base stations or by base station capabilities temporarily established by the user to support a specific project.

Real-time DGPS corrections can be transmitted via a separate communications path over limited distances (local area - DGPS) or over satellite links to much greater distances (wide area - DGPS). By continually monitoring and correcting satellite range errors, real-time DGPS offers the added benefit of providing an integrity check on the GPS satellites. Integrity is the ability to provide timely warnings to users when a satellite should not be used for navigation purposes. When a problem causes a GPS satellite to transmit bad data, real-time DGPS can continue to provide corrections or it can provide a message to not use the satellite in positioning or navigation computations. While the DOD's GPS master control station may take several hours to discover and correct problems with a given satellite, real-time DGPS can provide system integrity by notifying navigation and other users immediately that a satellite problem exists in its area of coverage. As a rule, the accuracy that can be obtained from real-time DGPS is proportional to the distance from the user to the monitor/reference site. Stationary users, less than a mile from the DGPS site, are able to arrive at positional solutions, over time, that have errors measured in centimeters, while mobile users can expect errors of 2-3 meters (ships and autos) or 3-5 meters (aircraft).

When GPS is used for measuring precise locations for geodetic monumentation or engineering surveys, a form of differential GPS called static relative positioning is used. Static positioning techniques use the carrier frequencies to achieve highly accurate differential measurements. These techniques require that two or more receivers observe the same satellites over a period of time. The collected data then requires post-processing to resolve unknown carrier phase shifts between satellite and receiver. Recent advances in GPS processing techniques and hardware have dramatically reduced the time requirements for performing static relative positioning.

Other highly precise GPS methods, known as kinematic positioning techniques, allow one receiver to move freely while another remains fixed. Kinematic GPS requires the roving receiver remain stationary for a short period of time at the start of the survey to allow initial unknowns to be resolved. As long as the GPS signals to either receiver are not interrupted, the roving receiver can achieve accuracy relative to static positioning techniques.

SECTION 2

PUBLIC AND PRIVATE SECTOR USES OF GPS

GPS APPLICATIONS INTRODUCTION

Global positioning system (GPS) capabilities have spawned new industries, vastly improved some existing applications, and have lead to the research and development of applications that could only be envisioned a few years ago. The information (location, direction, and velocity) capabilities provided by GPS have distinct advantages over its predecessors: all weather capability, 24 hour per day service, direct digital location data capture, unparalleled accuracy, lack of need for inter visible points, and real-time or post processing capabilities.

The unprecedented location accuracy available through GPS, along with the ability to determine velocity and direction has given rise to a wide variety of GPS supported applications in both the public and private sectors. Because of the rapid anticipated growth of applications that can use GPS technology and equipment, it is important that decision makers in both the public and private sectors gain a basic understanding of GPS technology, how it works with other related technologies and where they can be effectively applied to support organizational goals and objectives.

APPLICATION AREAS

The primary application areas that use GPS provided information are survey control, photogrammetry, GIS applications, and navigation. Decision makers and other potential users of this technology need to gain a basic understanding of each of these areas in order to determine how and where this technology could be utilized within their organizations. Within each of these application areas the user's requirements for information, accuracy, and timely delivery of information must be resolved prior to acquiring, designing, developing or implementing a specific application that uses GPS technology. Figure 4 provides guidance on the relative accuracy requirements that can normally be expected for applications developed in these primary areas.

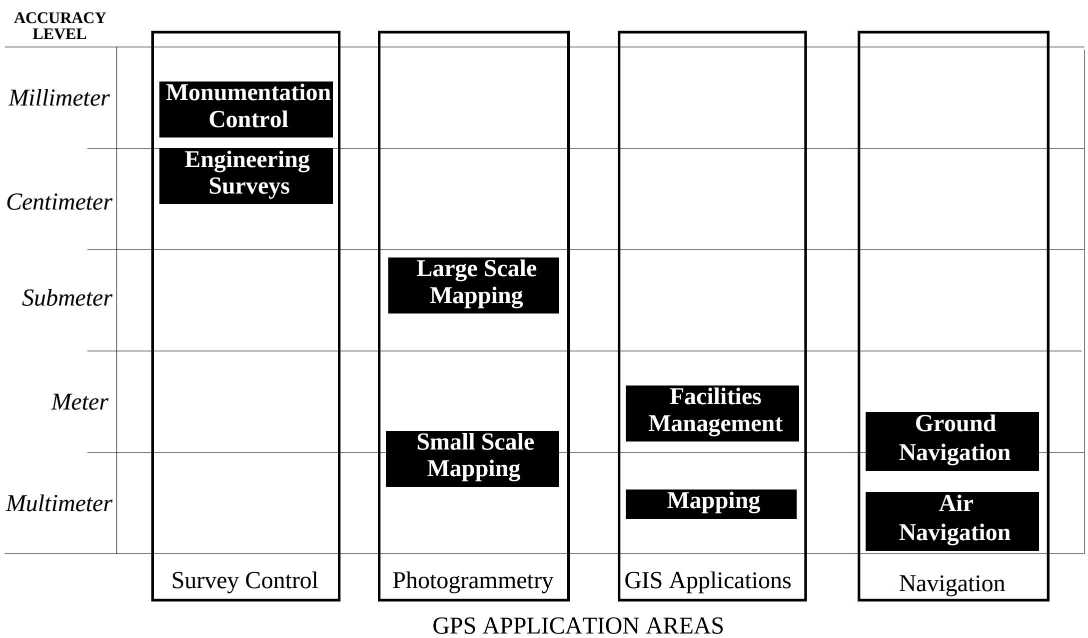
Survey Control

It is estimated that virtually all survey control work used to establish geodetic monumentation networks in the United States is being done with GPS equipment and conforms to the Federal Geodetic Control Subcommittee's (FGCS) standards and specifications. Surveying work and engineering applications such as establishing boundaries for aerial photographs and property/land parcels, and staking-out construction site coordinates may require accuracy of a centimeter or better. These accuracy requirements can only be met using the more expensive survey grade GPS equipment and software. In addition, this level of accuracy can only be achieved by determining the location points multiple times over an extended period of time using differential GPS correction methods. The primary users of GPS technology in this area are surveyors and professional engineers.

Photogrammetry

Technology advances in GPS, image processing, computer hardware, and aerial cameras make it operationally possible to use GPS in conjunction with aerial photographic collection for mapping applications. When GPS-augmented aerial photography becomes standardized in the industry, the aero-triangulation process will be expedited by having more control information available for stereo-model set-up, the ground survey costs will be reduced, and the overall quality control of the position information will be made easier and more complete.

Figure 4 - GPS Applications Relative Accuracy Chart



Facilities management usually includes mapping underground infrastructure (such as pipes, valves, and electric or communications lines) or physical building diagrams (such as an oil refinery) that require a great degree of accuracy.

Mapping includes the mapping of all other spatial data that does not normally require meter or better accuracy.

Source: R. Trott, J. K. Timmons & Associates (Jan/94)

GPS-augmented aerial photography reduces the ground survey costs by drastically reducing the amount of ground survey control and field work needed to produce a quality product. Some additional high accuracy ground control is required for most aerial photography projects and the most cost effective and timely method for establishing this control is to panel (marked with white crosses that are visible to the aerial camera) existing high accuracy geodetic control monuments. The primary users of this technology will be private sector aerial photography companies that provide aerial photographs, orthophotos, and digital orthophoto products. Most of these products are provided on a contract basis to federal, state and local government customers.

Several aerial photography vendors that operate on a national level currently offer GPS-augmented aerial photography services and it is expected that most major national and regional aerial photography vendors will be offering this service within the next two years.

Geographic Information Systems (GIS), GPS, and Mobile Computing

GPS is widely used by public and private sector organizations to electronically record the location of people, places, things and events at a point in time for later use in a host GIS environment. Accuracy ranges for this data capture function will vary with the application requirements and the GPS equipment used. Many state, regional, and local government mapping related tasks can be supported with this data capture method: mapping boundaries for state properties, parks and right-of-ways; mapping irregular boundaries of wetlands, lakes, and wildlife preserves; mapping the location of state and local government infrastructure such as street signs, bridges, guardrails, fire hydrants, street lights, water and sewer lines, manhole covers, and storm drains; and mapping the locations of accidents, fires, crimes, moving traffic violations, potholes, burned out street lights, missing or damaged traffic control signs or signals, and scheduled street or road maintenance boundaries. GPS can also be used to map the residence location of school children and school bus pickup points in support of school bus routing applications.

GPS can be linked to GIS by downloading the captured digital data into the GIS in a post processing mode, or it can be linked dynamically in a mobile computing environment with or without mobile communications capabilities.

Dynamic applications such as vehicle tracking, vehicle routing, emergency response, and field automation applications require GIS, GPS, mobile communications, and mobile computing equipment. These dynamic applications require accurate real-time location information, which is provided by real-time DGPS base statopms. GPS error correction information is received in a real-time mode from local area DGPS base stations or federal government operated DGPS sites and dynamically processed to dramatically improve the accuracy of the location determinations. In addition to providing the capability to receive the GPS error correction information, the mobile communications equipment provides the capability to send updates to and receive updates and directions from a central control site or from other remote computer systems. Most dynamic applications are managed through a central control system which uses GIS to monitor, track, analyze alternatives, and direct field operations through two-way mobile communications capabilities.

Agriculture. GPS/GIS controlled aerial applications of pesticides and fertilizers. Strict and automatic control of spraying can save money on the quantity of the chemicals being applied and the areas treated, and save time and effort by supporting automated field operations to meet the reporting and paperwork requirements for federal, state, and local government environmental regulating agencies.

Vehicle Tracking. Vehicle tracking applications have been developed and implemented for mass transit systems to determine location of buses, trolleys and rapid transit vehicles, monitor and adjust their schedules, dispatch maintenance crews for repairs, and to dispatch backup vehicles to move stranded passengers. Vehicle tracking applications are also being used to track the movement of sensitive cargoes (hazardous wastes, nuclear materials, and oversized loads) over the highways and railroads. Almost any organization that has a vehicle fleet could employ this technology to track the movement of its vehicles in a real-time or after the fact mode. Vehicle tracking applications use GPS to make location determination readings and combine those readings with either on-board or remote GIS's to track vehicle movement. The mass transit and sensitive cargo tracking applications usually combine mobile data communications with the GPS/GIS to dynamically track each vehicle's progress from a remote central control center.

Vehicle Navigation. Vehicle or land navigation systems have been developed and are being perfected that combine on-board GIS mapping capabilities with pre-loaded map information (roads, streets, political jurisdictions) and GPS technology. GPS provides the vehicle's location for processing by the GIS, which dynamically displays the vehicle's stopped or moving position on the underlying road map on a video screen mounted in the vehicle. Destinations, stops, and alternative routes can be pre-loaded into the GIS or they can be entered or changed by the vehicle operator. Currently car rental companies around Florida's Disneyworld are using this technology in their fleets to assist tourists find their way to Disneyworld attractions, hotels, restaurants, and other local spots of interest.

Emergency Vehicle Dispatching. The combination of GIS, GPS, and mobile communication technologies to support emergency vehicle dispatching is growing rapidly. Emergency control centers can use this combination of technologies to help manage the emergency vehicle and resources pool, determine the emergency site location either directly (E911) or indirectly (key in the address), locate the closest available needed resources, determine the shortest and quickest route to the emergency, dispatch the needed resources and track their progress until they have completed their mission and are returned to the active resource pool. Almost all emergency vehicles (police, fire, rescue) are equipped with mobile communications equipment which can be used to update the emergency control center with the vehicle's relative location for tracking and routing purposes. When these emergency vehicles are equipped with GPS receivers and mobile data communications capabilities they can be electronically linked with the emergency response control center to support dynamic vehicle tracking and routing. Dynamic tracking and routing capabilities permit quicker responses, add emergency vehicles and resources to the active resource pool quicker, and in times of disasters permit dynamic emergency vehicle routing around congested or impassable areas.

Public Safety Field Automation. The use of technology to support public safety field automation of accident reporting and vehicle/moving violations is being pilot tested by various state and local governments across the country. Figure 5 provides an example of multiple technologies being developed and tested in support of public safety operations and related field automation efforts. Field automation objectives include: reduce paperwork, increase accuracy, reduce staff time spent on completing paperwork, and increase reporting timeliness. These automation efforts require field staff be equipped with mobile data communications and computing capabilities to dynamically access remote computer systems on drivers, vehicles, and outstanding wants and warrants. Retrieved information can be formatted for reporting purposes (accidents, investigations, or tickets) and stored in on-board computers for processing at the end of the work day. Adding GIS and GPS can further reduce paperwork and data entry requirements for field staff by providing direct digital information for reporting purposes on the location of accidents, violations, or investigations, and the location description (route or street name, town, city, and county) from the GIS. Police can use mobile GPS units to map tire skid marks, the final location of all vehicles involved in an accident, and any other appropriate physical features relevant to an accident (i.e., traffic signals, intersections, trees, guardrails). GPS provided location information can be relayed to central control facilities for use in routing backup police, fire or rescue units. Automation of accident reports and traffic violations by field staff using GIS and GPS capabilities permit the direct downloading of this information into an organization's central GIS for analysis and consolidated reporting purposes.

Road Tracking and Maintenance. Governments involved in developing and maintaining the nations highway networks have shown great interest in the concept, development, and testing of vehicles designed specifically to map and capture descriptive information

Figure 5 - Technocar 2000

The Texas Transportation Institute (TTI) at Texas A&M University in College Station, Texas is developing and testing a high technology prototype vehicle for possible use in law enforcement applications. The project is sponsored by the Texas Department of Transportation in cooperation with the Texas Department of Public Safety (DPS) and private sector vendors. The TC2000 prototype vehicle is a standard DPS pursuit vehicle equipped with DPS-specified "police package" options, including DPS-issue communications, radar, and other emergency equipment.

The primary goal of the project is to improve the quality and timeliness of traffic records data in Texas by evaluating new technologies for traffic safety applications. Each year TxDOT makes more than $350 million in funding decisions based on traffic safety records. It is critical that this information be timely and accurate, but it is increasingly expensive to collect. These data must be collected in a more efficient manner at a significant cost savings to the public without endangering officer safety. Other project goals include: enhance an officer's ability to collect data quickly and efficiently; improve location identification accuracy; provide the officer at the scene with a fast and easy interface between sources of information such as driver's license record files, vehicle license plate and registration files, criminal records, and wants and warrants; evaluate whether automated data collection technology for law enforcement will work under field conditions; and improve the accuracy and timeliness of traffic safety data.

The prototype vehicle contains the following equipment mounted on specially manufactured mounts for easy access and removal for use in the field by an officer.

- A hand-held battery powered pen system computer that runs off of the vehicle's power system when mounted in the car. The keyboard and a small laser printer are mounted in the vehicle. The pen computer support field automation of the Texas accident report form, DPS citation form, and the DPS commercial vehicle inspection form An officer uses the pen system computer to collect data, communicate with the vehicle's mobile modem using spread spectrum technology, which in turn communicates with base personnel and computers through the mobile modem operating over a two-way radio system. A base modem receives data and interfaces with the DPS criminal justice information network and various records divisions including the Department of Motor Vehicles.

- A device that attaches to the pen computer for use in reading magnetic strip information soon (1995) to be contained on Texas driver's licenses. The pen computer will transmit the scanned information for verification and retrieval purposes while filling in the current form displayed on the pen computer.

- A device that attaches to the pen computer as a wand that can be used to read bar codes on inspection stickers and vehicle identification numbers (VINs). Within a few years, Texas vehicle registration information will be contained on a sticker that attaches to the vehicle's windshield.

- A global positioning system (GPS) receiver and interface software for the pen computer system that will collect and store GPS determined location coordinates at accident scenes.

- A mobile video taping (MVT) system mounted on the vehicle's dash that can be powered on manually or that automatically comes on when the vehicle's overhead emergency lights are turned on. This system should be very useful for DUI/DWI incidents, or as a detached mobile information collection device at an accident or investigation site. In the future, it is anticipated that MVT images could be digitized and become part of the permanent database records, admissible in court.

One of the key evaluation criteria for employing high technology in law enforcement field operations is the interaction between an officer and the technology during field conditions. After testing in a controlled environment on the Texas A&M Riverside Campus, the equipment will be installed and tested in the College Station Police Department and Bryan District DPS vehicles. TTI researchers will train the officers how to use the equipment and then ride with them to observe how the officers interact with the technology. At the end of the first phase of this project, a final report will be published by TTI containing the findings of the evaluations, including any appropriate recommendations, and a videotape will be produced of the project in progress. The next phase of the TC2000 project will examine the previous technologies as they mature as well as additional new technologies such as biometric identification, capture of video images into the database, heads-up displays, IVHS (Intelligent Vehicle/Highway System) interfaces, voice-activated equipment, enhanced vehicle design, and applicability for installation on a police motorcycle.

Source: Texas Transportation Institute, Texas A&M University System, College Station, Texas and/or video images of a highway as it is being driven. These vehicles can be equipped with a wide variety of technology and are normally referred to as road tracking vehicles. Potential uses for road tracking vehicles include mapping road and street centerlines and creating corresponding road log video images for the mapped roads. Vibration monitoring devices can also be linked with the road mapping equipment and used to map the relative roughness of the surface of the roadway being traveled. By matching the vibration readings to traveled road surfaces, GIS can be used to determine sections of road surfaces that should be re-surfaced because of extremely rough conditions or road sections that should be inspected for possible maintenance or re-surfacing scheduling. The roughness of road surfaces could also be used as evaluation criteria for annual and long-term highway inspection and maintenance programs at the state and local government levels. Road tracking vehicles can be equipped for dynamic location determinations or the collected information can be downloaded and post processed to improve the accuracy of the location information. In the latter, GPS error correction information saved at the nearest GPS base station can be matched to the satellites tracked by the road tracking vehicle's GPS and processed to improve the accuracy of the collected location information.

Navigation

Originally the GPS system was developed to assist the various military branches' air, land and sea navigation and timing requirements. Since then, many air, land, and marine applications have been developed to support public and private sector navigation needs.

Air Navigation. Air navigation using GPS presents opportunities for standardized worldwide civil aviation operations using a common navigation receiver with resulting improvements in safety, capacity, service, and operations costs. When aerial navigation receivers are coupled with radio linked differential base stations, they can provide the required dynamic location accuracy needed to support such applications as runway alignment and precise landing approaches. In addition, it is projected that commercial GPS controlled aircraft collision-avoidance systems and auto pilots will soon be available.

Marine Navigation. The SPS of GPS will provide marine navigators with the first precise, worldwide, continuous positioning and timing service. SPS, augmented with real-time DGPS, will satisfy the most stringent marine accuracy requirements for harbor and harbor approach navigation, that have previously been attainable with other radio navigation systems. Marine navigation capabilities range from determining a relative position to GPS auto pilots displaying real-time location on a color graphic display with a CD ROM chart drive providing a moving map background. The U. S. Coast Guard is erecting a number of real-time DGPS base stations along the coast that provide the 8-20 meter accuracy capability necessary for inner harbor navigation.

Land Navigation. Many state and local government applications and operations could use land navigational capabilities to physically locate things or places that have been previously mapped. State, city, and county maintenance crews could be dispatched to specific locations to fix potholes, replace and paint guardrails damaged in an accident, or remove trees from roadways or electrical lines. Federal, state and local government inspection officials could be dispatched to the specific locations of underground storage tanks, wells, or abandoned mines for inspection purposes.

STATE AGENCY APPLICATIONS

Several state agencies are using or have plans to use GPS to support applications in all the primary application areas presented in this section. In addition most of these applications are or will be combined with GIS, mobile computing and mobile communications.

Installed GPS Related Applications

Survey Control. The Virginia Department of Transportation (VDOT) is by far the largest state agency user of GPS technology. VDOT has used GPS for a number of years to provide survey control monumentation to support its aerial photography, right-of-way acquisition, corridor study, and highway design and construction responsibilities. The primary benefit attributed to the use of GPS in VDOT has been increased survey crew productivity (more work, with greater accuracy, in a shorter time frame).

Guidance for Med-Flight Helicopters. The State Police have acquired two new med-flight helicopters that are equipped with GPS/Loran guidance systems. The med-flight helicopters use their guidance systems to find the landing site (usually the nearest intersection) nearest an accident. The landing site coordinates are coordinated through and provided by the Department of Emergency Services.

Forest and Forest Fire Management. The Department of Forestry field tested hand-held GPS receivers in 6 field offices during 1993. The pilot project was used to acquaint field personnel with the equipment and its capabilities. Field staff surveyed known points with GPS and verified the results by checking the corresponding professional survey results for those points in local government land records offices. The Department plans to eventually have at least one GPS unit in each of its 65 field offices. Based on encouraging results from the field tests, the initial GPS units are being deployed in the field offices for use in point determinations in timber harvesting and management, forest fire location determinations, and pond locations for the Department's dry hydrant program. The point determinations are currently used for manual reports with the expectation this information will later be converted for use in a Department GIS. GPS will be used to support the Department's fire control, other agencies coordination, and long-term forestry management responsibilities. GPS is particularly well suited to support the Department's field staff because most of their work is in relatively remote areas of the Commonwealth that have few well defined landmarks. GPS will permit field staff to quickly and accurately determine point locations and map areas at reduced costs with fewer field resources.

Well Head and Ground Water Management. The Department of Environmental Quality's Water Division has been testing hand held GPS receivers to map and locate well heads, ground water monitoring locations and equipment, and ground water sampling points. The pilot test objectives were to determine GPS's suitability for use in district offices and its ability to meet Federal mandated accuracy requirements for water monitoring. The pilot test included two (2) GPS units with one unit being used for the mapping and point location work while the other unit served as a base station to minimize GPS error factors. The pilot test demonstrated the effectiveness of GPS under field conditions and verified its ability to exceed Federal accuracy requirements. Potential benefits identified include increased field staff productivity with more accurate and timely location information. The Water Division does not currently have funds to acquire GPS equipment for its district offices.

Flood Warning Devices Inventory. The Department of Emergency Services' field staff are using GPS to determine the precise location of each early warning device tied into the Integrated Flood Warning System. Knowing the precise location of each warning device provides better flood location information for the early warning system, supports the warning device inventory control function, and provides precise location information for GPS equipped repair crews to find and fix or replace non-functional or missing warning devices, potentially saving lives, time, and money.

Planned GPS Related Applications

GPS Road Tracking. VDOT will test GPS road tracking capabilities (ability to accurately map road and street center lines from a moving vehicle) to determine its viability and effectiveness for developing the statewide roads and streets common data layer for the Virginia Geographic Information Network (VGIN).

Figure 6 - State Agency GPS Applications

STATE AGENCIES	Engineering Surveys	Monument-ation Control	Large Scale Mapping	Small Scale Mapping	Facilities Management	Mapping	Ground Navigation	Air Navigation
Dept of Transportation	installed	installed	installed	installed		planned		
Dept of Environment Quality						installed		
Dept of Forestry						installed		
Dept of Emergency Services						planned	planned	installed
Dept of Game & Inland Fisheries						planned		
Dept of Aviation								planned*
Marine Resource Commission		planned				planned		
	Survey Control		Photogrammetry		GIS Applications		Navigation	

G P S A P P L I C A T I O N A R E A S

* joint planning with NASAO and the FAA to establish GPS base stations at aviation facilities

Source: CIM Staff 1994

Runway Alignment. The Department of Aviation is participating in a joint planning effort with the National Association of State Aviation Officials (NASAO) and the FAA to establish real-time DGPS base stations at aviation facilities across the country. The FAA will provide the design for approaches for all aviation facilities across the county. The FAA will also provide the necessary base stations to cover the approaches for all eleven (11) commercial aviation facilities in Virginia. The Department of Aviation will be responsible for providing additional DGPS base stations to handle the approaches to other Virginia aviation facilities not covered by FAA base stations. Initial FAA plans call for the implementation of the non-precision approach (horizontal coordinates only) base stations in 1994-95, with the precision approach (horizontal and vertical coordinates) tentatively scheduled for around the year 2000. The non-precision approach will supplement current aircraft navigation systems by providing runway alignment information.

Inventory of Endangered Species. The Department of Game and Inland Fisheries has completed an evaluation of GPS technology and identified several potential uses for the technology. GPS could be used by field staff to capture point location information or map areas to support the Department's management, protection, tracking and inventory responsibilities relating to endangered species, fish, and wildlife sanctuaries. Potential benefits include the ability to capture accurate and timely digital information for input into the Department's Arc/Info GIS that is used for agency inventory, management, and analysis purposes. The Department has identified the need for, but lacks funding for, a minimum of four (4) GPS receivers for use by field staff that support its Land & Engineering, Fish, and Wildlife Divisions, and its central GIS function.

Search and Rescue. The Department of Emergency Services has been field testing and identifying potential uses of hand-held GPS receivers in its Search and Rescue Units since the middle of 1993. The Search and Rescue Units are responsible for coordinating search and rescue efforts for lost aircraft and people. GPS could be effectively used by field staff to capture (mark) the location of any aircraft debris or victims found in and around a crash site for later use by recovery teams and accident review teams. GPS could also be used to coordinate search team activities and manage search and rescue operations over large remote geographic areas. Search and rescue teams in the field could use GPS to find their precise assigned starting points in a controlled grid search and use portable two-way radios to communicate searched area coordinates to the central control facility that has overall responsibility for coordinating the search and rescue operation. In addition, search and rescue teams can relay their GPS determined position to recovery aircraft who can use their Loran systems or GPS to quickly find the search team for rescue or evacuation purposes. The ability of recovery aircraft to quickly find a search team or victim in remote areas in emergency situations can save lives, reduce search team recovery times and overall operations costs.

Eastern Shore Survey Control Network. The Marine Resources Commission (MRC) recently received a federal grant to purchase GPS equipment and processing software. The MRC requested funds for a pilot project (covered by four 1:5,000 scale maps in the Cedar Island area) that will use GPS to build a network of survey stations east of the mainland of the Eastern Shore, throughout the islands to and along the barrier islands. This survey network will establish the coordinates of known points that can be relocated after storms or overwashes occur. This network will provide the most efficient way for the MRC to maintain the boundaries between private and state-owned property. The pilot project will also be used to determine survey stations for the oyster ground lease surveys in the project area. The MRC plans to acquire additional GPS equipment after the pilot has been completed and expand its use to support its water body, shoreline, and oyster bed boundary determination responsibilities. The MRC plans to use the GPS captured digital location information in its Arc/Info GIS, in particular to support its oyster bed leasing and management functions. The ability to survey, map, and locate specific points in areas where all or some of the previous known physical features may have been destroyed by storms or overwashes has been identified as the primary benefit of GPS to the MRC.

SECTION 3

GPS RECOMMENDATIONS AND DIRECTIONS

SUITABILITY OF USE

Section 2 provided an overview of how and where GPS capabilities can and are being used in the public and private sectors. It is expected that the market for GPS technology will continue to grow at a rapid pace and the capabilities of the GPS equipment and corresponding software will continue to evolve and improve. It has been estimated that by the year 2000 approximately 100,000 Americans will be working in what should be a $5 billion GPS industry. As more and more public and private sector organizations increase their use of geographic information systems to support a wide variety of operational and decision support applications, GPS is expected to become the preferred data capture method for providing accurate location information to meet a wide range of requirements related to places, things, and events.

Many public and private sector organizations will benefit from the use of GPS technology through improvements in the accuracy, timeliness, and quality of location information; increased staff productivity; and through their ability to support field staff information collection and automation efforts. To ensure these benefits, public and private sector organizations must: effectively use federal government provided GPS and DGPS capabilities; match application requirements to GPS capabilities; establish standards and procedures for GPS services and setting geodetic monuments; and take advantage of technology advancements such as GPS-augmented aerial photography.

FEDERAL DIRECTIONS FOR CIVIL GPS USES

In 1983, following the downing of Korean Airline Flight 007, President Reagan directed that the Department of Defense (DOD) operated GPS be made available by the Department of Transportation (DOT) for international civil use. Subsequently, the DOD formally requested that the DOT assume responsibility for interfacing with the civil community and work closely with the DOD to ensure proper implementation of GPS for civil use. As part of its efforts to promote the international civil use of GPS, the United States in 1991 offered the GPS Standard Positioning Service (SPS) for air navigation purposes to other nations at the Tenth Air Navigation Conference. The specific offer was:

> *"SPS is planned to be available beginning in 1993 on a continuous, worldwide basis with no direct user charges for a minimum of ten years. The service will provide horizontal accuracies of 100 meters (2 drms - 95% probability) and 300 meters (99.99% probability)."*

In September 1992, the United States extended the 1991 offer and offered SPS to the world for the foreseeable future and, subject to the availability of funds, to provide a minimum of six-year advance notice of termination of GPS operations or elimination of the SPS.

The Departments of Defense and Transportation have been working closely in the development and implementation of GPS for both civilian and military uses. In

December, 1993, a Joint DOD/DOT Task Force report to the Secretaries of Defense and Transportation contained several recommendations relating to the management and operation of GPS for civilian uses:

- The Department of Transportation should create an executive committee that will meet regularly with its DOD counterpart to discuss GPS policy and management issues. An Assistant Secretary of Transportation should be designated Chairman of the new committee and be delegated authority to: speak on behalf of the civil GPS user community; make decisions for the DOT regarding civil GPS services; and maintain an outreach program to ensure that the needs of other federal agencies, state, and private sector users are addressed in future GPS decision-making processes.

- Differential GPS (DGPS) services should be implemented for those civil applications requiring accuracy better than that provided by GPS SPS, with or without Selective Availability (SA) or by GPS Precise Positioning Service (PPS).

- A wide area broadcast using communications satellites should be implemented as an expeditious way to rapidly improve GPS integrity and availability for aviation users, and possibly other modes of transportation. This wide area broadcast should include both integrity and ranging components. Integrity information should be provided along with all DGPS services.

- Private sector-provided DGPS services not used for navigation purposes should not be regulated. However, the government should retain the option to regulate private sector-provided DGPS services should they be used for navigation in the future.

The United States is committed to making the SPS service of GPS available for civil users through the Department of Transportation. There are three agencies within DOT that interface with DOD on GPS matters: the U.S. Coast Guard; the Federal Aviation Administration (FAA); and the Research and Special Programs Administration (RSPA).

U.S. Coast Guard - the Coast Guard is the lead DOT agency for civil GPS service operations and the government interface with civil users of GPS. The Coast Guard is empowered to prescribe and enforce rules and regulations relating to private maritime aids to navigation. These rules and regulations prohibit the operation of private electronic aids to maritime navigation, with the exception of radar beacons and shore-based radar stations. The Coast Guard is installing a real-time DGPS base station network which will cover the coasts of the U.S.--including the Great Lakes, much of the coasts of Alaska and Hawaii, and U.S. inland waterways. This DGPS network will satisfy current marine navigation requirements and has potential utility for land users within range of its signals. The Coast Guard operates a GPS Information Center (GPSIC) through which all users can obtain general and status information for the GPS as well as for other Coast Guard operated radio navigation systems. The Coast Guard is also establishing a Civil PPS Program Office (202 267-0298) to process applications for civil access to the PPS service of GPS.

GPSIC contact

Commanding Officer
U.S. Coast Guard ONSCEN
7323 Telegraph Road
Alexandria, VA 22310-3998
(703) 313-5900

Federal Aviation Administration - the FAA is responsible for aviation matters for the National Airspace System (NAS). The use of private radio navigation services for aviation use is strictly controlled by the FAA through stringent certification standards. The FAA has granted some airport operators authority to employ privately owned radio navigation aids for air traffic control and this practice is expected to expand with the increased use of DGPS. Currently the GPS SPS signal satisfies the civil aviation accuracy requirements for oceanic, en route, terminal, and nonprecision approach operations. For precision approach and landing, and airport surface traffic control, the basic SPS signal does not satisfy requirements in the areas of accuracy, coverage, and integrity. Currently, the FAA is planning a phased approach for implementing real-time DGPS capabilities at commercial airports to meet the civil requirements for these more exacting phases of flight operations.

Research and Special Programs Administration - the RSPA coordinates issues and planning of an intermodal nature.

GPS EQUIPMENT

Market trends for GPS technology indicate a dynamic marketplace with vendors continuously offering new or upgraded receivers and processing software that provide increased functionality and accuracy at reduced costs. Figure 7 provides an estimated cost range for GPS equipment and processing software normally required to support applications in survey control, photogrammetry, GIS, and navigation.

At a minimum, an organization considering acquiring GPS equipment should document its requirements for location dependent information in sufficient detail to determine the minimal accuracy requirements for each application to be supported and to determine any related requirements for real-time GPS capabilities. Accuracy and real-time GPS support requirements are essential information for evaluating the GPS marketplace, determining what if any GPS technology can meet the organization's requirements, and developing alternative GPS solutions, including cost estimates.

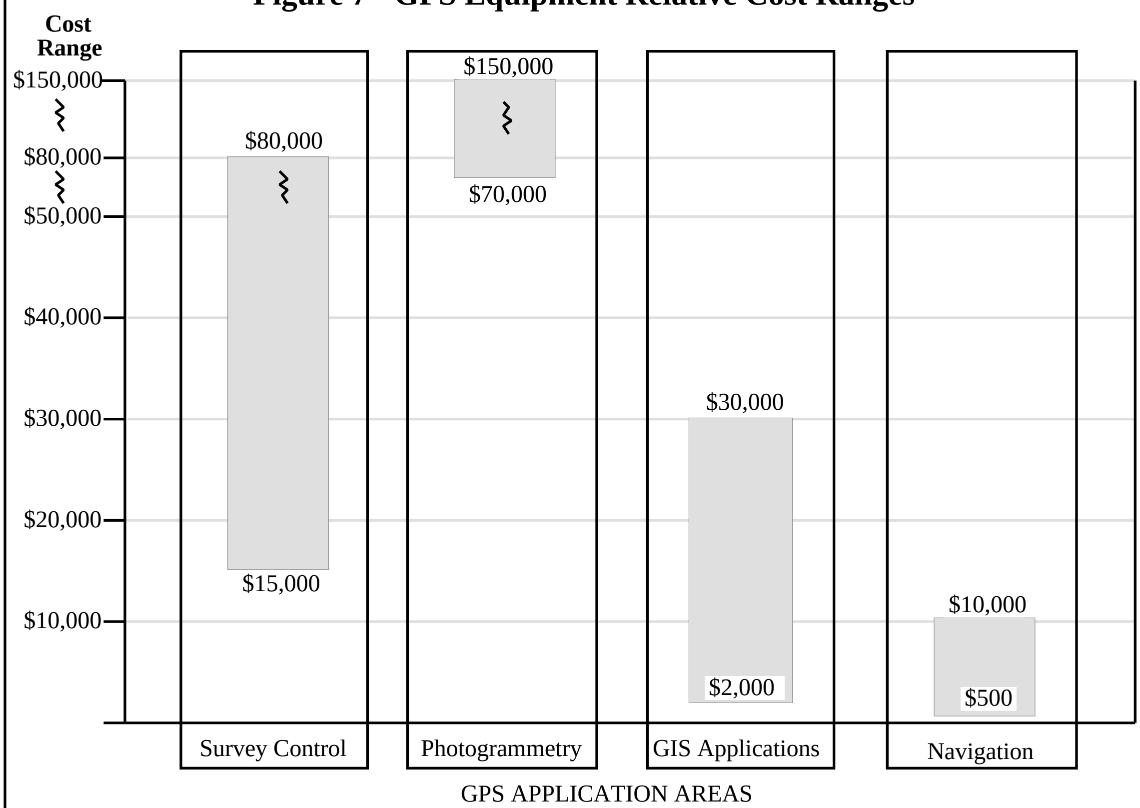
Accuracy Requirements - The location dependent information accuracy requirements for a specific project, program or application can be influenced by a number of variables. These variables can include such things as: the intended use of the location determinations (i.e., legal document for property rights, calculation of acreage to estimate agriculture crop yields, etc.); federal, state, or local government mandates; and established accuracy levels for manual maps or automated GIS base maps. Determining an organization's minimal accuracy requirements is the key component in evaluating the potential use of GPS technology.

Real-time GPS Capabilities - In addition to determining the minimal accuracy requirements required to support each specific application, an organization should also determine if any of the applications require real-time GPS capabilities. Requirements for real-time GPS capabilities, when combined with the minimum accuracy requirements will further reduce an organization's options for GPS equipment and processing software and may require permanent real-time DGPS base station capabilities to meet the accuracy requirements. Organizations that require real-time DGPS base station capabilities should, whenever possible, use DGPS signals available through or regulated by the U. S. Government. Private sector organizations are prohibited by U.S. Government regulation from providing unregulated real-time DGPS signals for navigation purposes.

Once minimal accuracy requirements and real-time GPS requirements have been determined, an organization can evaluate GPS technology to determine its capability to meet the accuracy requirements, with or without, differential correction capabilities in a real-time or post-processing mode. Organizations requiring differential correction (real-time or post processing) will have to consider various alternative means and associated costs for providing these capabilities including:

- the availability of permanent base stations;
- the establishment of new permanent base stations; and
- the use of temporary base stations.

Figure 7 - GPS Equipment Relative Cost Ranges



Survey Control *- assumes 2 receivers, antennas and post processing software. The low end assumes submeter receiver systems and the high end assumes dual frequency receivers, centimeter or better accuracy, and rigorous post processing software.*

Photogrammetry *- GPS-augmented aerial photography requires GPS equipment and software specifically adopted for airborne use. The low end assumes 1 GPS unit on-board the aircraft and 1 unit on the ground, while the high end assumes 2 units on-board the aircraft and 2-4 units on the ground depending on the size of a given project.*

GIS Applications *- the low end assumes a single receiver, 100 meter positional error with 25-50 meter probable error and the high end assumes 2 receivers, differential correction, high volume data logging, mapping and output capabilities.*

Navigation *- the low end assumes 1 receiver for point positioning and the high end assumes 2 receivers, or 1 receiver with remote access, and real time differential correction capabilities.*

Source: Photo Science, Inc., Trimble Navigation, Inc., Magellan Systems Corp., Michael Barker Jr., Inc., J. K. Timmons & Associates (Feb/94)

Other Considerations. Staff or organizations that are involved in the collection and/or creation of location dependent information on a continuous basis should be considered prime candidates for using GPS technology. Examples include surveyors, construction or highway engineers, aerial photography vendors, and field staff that collect and report location dependent information (accidents, crimes, and water samples). It is possible that investments in GPS technology to support the normal activities of these types of organizations and staff may be justified strictly through increased staff productivity.

State agencies that are evaluating or planning to acquire major in-house GPS capabilities should complete a cost/benefits analysis to determine the feasibility, cost effectiveness, and the benefits to be derived from using GPS technology to support their organizational missions. The GPS technology alternatives and associated cost estimates that are developed from the requirements and the GPS marketplace evaluation provide essential information required for any effective cost/benefits analysis.

GPS RELATED STANDARDS AND SPECIFICATIONS

Public sector organizations involved in densifying or developing geodetic control networks should adopt the following as standards:

- **GPS services** should conform with the Federal Geodetic Control Subcommittee's (formerly FGCC) *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques* (Version 5.0 dated May 11, 1988 and reprinted with corrections, dated August 1, 1989.)

- **Horizontal and vertical accuracy for geodetic monuments** must comply with the FGCS order and class as specified in the table on *Geodetic Relative Positioning Accuracy Standards for Three-dimensional Surveys Using Space System Techniques* contained in the FGCS *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques* (Version 5.0 dated May 11, 1988 and reprinted with corrections, dated August 1, 1989.).

- **Geodetic monuments** must comply with FGCS ***Standards and Specifications for Geodetic Control Networks*** (September, 1984)

Copies of these documents can be ordered from:
NOAA, National Geodetic Survey, N/CG17
SSMC3, Station 09202
Silver Spring, Maryland 20910
Phone (301) 713-3242
Fax (301) 713-4172

Appendix B contains a model request for proposal (RFP) to procure professional surveying services for horizontal control monuments using GPS technology. Appendix B provides an outline request for proposal that can be modified to meet the particular horizontal control monument requirements of public and private sector users. It includes appropriate references to the above standards and specifications for GPS services and horizontal and vertical accuracy for geodetic monuments.

RELATED AERIAL PHOTOGRAPHY CONSIDERATIONS

Currently, aerial photography as used in both the public and private sector organizations requires considerable ground control and paneling efforts to produce quality products. In the near future, it is expected that the demand for new digital orthophotographs and softcopy mapping products that require even more ground control will increase rapidly in public sector organizations. Governmental organizations can decrease the overall ground control and paneling requirements normally associated with aerial photography projects by expanding the use of their geodetic control networks and taking advantage of GPS-augmented aerial photography capabilities.

Ground Control and Aerial Photo-Identifiable Points

As geodetic control monuments are being planned and established throughout Virginia, state agencies, local governments and private sector organizations should consider whether such points are easily identifiable from the air for aerial photography purposes. Whenever possible all high accuracy monuments in geodetic control networks should be in locations where they can easily be paneled (marked with white crosses) prior to future photographic missions, and be easily accessible, preferably by a motor vehicle.

Coordinating the establishment of a statewide geodetic control network that supports both ground survey control and aerial photographic uses will provide the means to reduce ground control costs associated with future aerial photography projects and will enhance the accuracy of Virginia geographic information developed for public and private sector users. To ensure the effective use of those monuments that support both ground survey control and aerial photographic uses, governmental organizations that establish these monuments should collect, maintain, and distribute the information needed to identify all such monuments to public and private sector users.

Statewide geodetic control network information will be collected, maintained, and distributed as part of the Survey Control common data layer of the Virginia Geographic Information Network (VGIN). The Virginia Department of Transportation has been identified as the responsible agency for this VGIN common data layer.

GPS-Augmented Aerial Photography

GPS-augmented aerial photography services are commercially available to meet the needs of public and private sector organizations. However, there are no widely accepted standard operating procedures for these services that cover all of the major elements of aerial photography using GPS. While GPS-augmented aerial photography has been proven to work, any public or private sector organization considering procuring these services must take appropriate steps to ensure that a selected vendor's procedures are adequate and that the vendor is willing to warrant that the GPS-augmented aerial photography will meet the organization's specified accuracy and quality requirements.

Appendix A

Glossary of GPS Terms

Anywhere fix - the ability of a receiver to start position calculations without being given an approximate location and approximate time.

Bandwidth - the range of frequencies in a signal.

C/A code - the standard (Course/Acquisition) GPS code --- a sequence of 1023 pseudo-random, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code".

Carrier - a signal that can be varied from a known reference by modulation.

Carrier-aided tracking - a signal processing strategy that uses the GPS carrier signal to achieve an exact lock on the pseudo-random code. More accurate than standard approach.

Carrier frequency - the frequency of the unmodulated fundamental output of a radio transmitter.

Channel - a channel of a GPS receiver consists of the circuitry necessary to tune the signal from a single GPS satellite.

Chip - the transition time for individual bits in the pseudo-random sequence. Also, an integrated circuit.

Clock bias - the difference between the clock's indicated time and true universal time.

Control segment - a world-wide network of GPS monitoring and control stations that ensure the accuracy of satellite positions and their clocks.

Cycle slip - a discontinuity in the measured carrier beat phase resulting from a temporary loss-of-lock in the carrier tracking loop of a GPS receiver.

Data message - a message included in the GPS signal which reports the satellite's location, clock corrections and health. Included is rough information on the other satellites in the constellation.

Differential positioning - precise measurement of the relative positions of two receivers tracking the same GPS signals.

Dilution of Precision - the multiplicative factor that modifies ranging error. It is caused solely by the geometry between the user and his set of satellites. Known as DOP. There are many DOPs - PDOP, HDOP, VDOP, TDOP and GDOP).

Distance Root Mean Square (drms) - the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. As used in this document, 2 drms is the radius of a circle that contains at least 95 percent of all possible fixes that can be obtained with a system at any one place.

Doppler-aiding - a signal processing strategy that uses a measured doppler shift to help the receiver smoothly track the GPS signal. Allows more precise velocity and position measurement.

Doppler shift - the apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Ellipsoid - the three-dimensional mathematical approximation of the earth's surface at sea level. The World Geodetic System of 1984 (WGS 84) ellipsoidal model is used as the basis for GPS satellite data and measurements.

Ephemeris - the predictions of current satellite position that are transmitted to the user in the data message.

Fast-multiplexing channel - a single channel which rapidly samples a number of satellite ranges. "Fast" means that the switching time is sufficiently fast (2 to 5 milliseconds) to recover the data message.

Fast or rapid static surveying - GPS techniques utilizing dual frequency carrier phase and code measurement and processing techniques, reducing observation times for static surveys from approximately one hour to 5-10 minutes.

Frequency band - a particular range of frequencies.

Integrity - Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

Ionosphere - the band of charged particles 80 to 120 miles above the earth's surface.

Ionospheric refraction - the change in the propagation speed of a signal as it passes through the ionosphere.

Kinematic positioning - differential positioning techniques consisting of carrier phase measurement and static initialization to resolve integer ambiguities. Yields centimeter level accuracy for a roving receiver at observation intervals of one second or better.

L-band - the GPS radio carrier frequencies are ***L1*** -1575.42MHz and ***L2***-1227.60MHz which are in the L band.

Multipath error - errors caused by the interference of signal that has reached the receiver antenna by two or more different paths. Usually caused by one path being bounced or reflected.

Multi-channel receiver - a GPS receiver that can simultaneously track more than one satellite signal.

Multiplexing channel - a channel of a GPS receiver that can be sequenced through a number of satellite signals.

National Airspace System (NAS) - the NAS includes U.S. airspace; air navigation facilities, equipment and services; airports or landing areas; aeronautical charts, information and service; rules, regulations and procedures; technical information; and labor and material used to control and/or manage flight activities in airspace under the jurisdiction of the U.S. System components shared jointly with the military are included in NAS.

Nonprecision Approach - a standard instrument approach procedure in which no electronic glide scope is provided.

P-code - the Precise or Protected code. A very long sequence of pseudo-random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz which repeats about every 267 days. Each one week segment of this code is unique to one GPS satellite and is reset each week.

Precise Positioning Service (PPS) - the most accurate dynamic positioning possible with GPS, based on the dual frequency P-code.

Precision Approach - a standard instrument approach procedure in which an electronic glide scope is provided; e.g., the Instrument Landing System (ILS).

Pseudolite - a ground-based differential GPS receiver which transmits a signal like that of an actual GPS satellite and can be used for ranging. The data portion of the signal contains the differential corrections that can be used by other receivers to correct for GPS errors.

Pseudo-random code - a signal with random-noise like properties. It is a very complicated but repeated pattern of 1's and 0's.

Pseudorange - a distance measurement based on the correlation of a satellite transmitted code and the local receiver's reference code, that has not been corrected for errors in synchronization between the transmitter's clock and the receiver's clock.

Radio Navigation - the determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Satellite constellation - the arrangement in space of a set of satellites.

Space segment - the part of the whole GPS system that includes the satellites and the launch vehicles.

Spread spectrum - a system in which the transmitted signal is spread over a frequency band much wider than the minimum band-width needed to transmit the information being sent. For GPS, this is done by modulating the carrier with a pseudo-random code.

Standard positioning service (SPS) - the normal civilian positioning accuracy obtained by using the single frequency C/A code.

Static positioning - location determination when the receiver's antenna is presumed to be stationary in the earth. This allows the use of various averaging techniques that improve accuracy by factors of over 1,000.

User interface - the way a receiver conveys information to the person using it. The controls and displays.

User segment - the part of the whole GPS system that includes the receivers of GPS signals.

Appendix B

Model
Request for Proposal

(Horizontal Control)

Components

RFP Posting Notice

Letter to Prospective Vendors

Project Description

Applicable GPS Standards

Outline Format and Content for Vendor Responses

Notice to Users Example

RFP Posting Notice

RFP Notice (as required for procurement posting purposes)

Specify Issuing Organization Name and Address

REQUEST FOR PROPOSAL

Horizontal Control

for *specify descriptive project name*

The *specify organization name* will receive proposals for the provision of horizontal survey control and related services in connection with the *specify descriptive project name*.

Proposals will be accepted in *specify exact location, office, etc.* until s*pecify exact time and date*.

There will be a Pre-Proposal Meeting held at *specify exact location, office, etc.* on s*pecify exact time and date*. Vendor questions will be answered at this time only.

Firms desiring to be considered for this work must submit *specify the number of copies needed* copies of their proposal showing evidence of their qualifications and experience to perform the required services.

For further information or copies of the this Request for Proposal, contact *specify name, division, section, address, and telephone number*.

Letter to Prospective Vendors

(letter should use the appropriate letterhead)

(date)

Re: Request for Proposal (RFP), Professional Surveying Services - Horizontal Control - *specify descriptive project name*.

Vendors:

The *specify organization name* is seeking a qualified vendor to provide certain professional services for the above named project (project description is attached).

Proposals from interested vendors are requested and shall include statements of interest, ability to complete the work within the required time, experience, and qualifications. Certain firms have been selected to receive this RFP. However, all qualified firms are invited to submit proposals.

There will be a single Pre-Proposal Meeting held at *specify exact location, office, etc.* on s*pecify exact time and date*. Vendor questions will be answered at this time only.

Vendor proposals in response to this RFP will be received by *specify person, organization, and location* until *specify exact date and time*. Interviews and/or proposal presentations may be scheduled for selected vendors responding to this RFP.

Your participation in this procurement is appreciated.

Sincerely,

issuing authority name
title
organization

Attachments

Project Description

Project: *specify descriptive project name*

Project Location: *provide description and/or a hardcopy location map*.

Scope of Project: Provide a *specify areas* Horizontal Geodetic Control Network utilizing Global Positioning System technology for use in support of *provide an appropriate description*.

Scope of Services:

1. Preliminary Phase: Determine the number and approximate location of the monuments required in a network to support *provide scale requirements and appropriate project description*. Perform reconnaissance to determine usability of monuments for GPS differential surveying. *Specify other project requirements or intended uses such as: Select GPS points as being identifiable for future aerial photography projects if possible. When the photography is to be collected in the near-term and a point is not an obvious feature on the ground, it is standard procedure to target all such points (monuments) with fabric material and remove the fabric after completion of the photography.*

2. Survey Phase: In accordance with the *specify appropriate standards/procedures* perform GPS field work, office post processing and final adjustment for differential survey on approximately *specify number* monuments. *Provide additional information on the monuments including: # of new monuments, existing monuments, locations, etc.*

3. Final Report Phase: Prepare Reference/Recovery sheets *provide and example of the required format and specify any specific software processing requirements* for all monuments occupied, *specify scale requirements for* a reproducible project schematic designating the control monument locations and a final GPS report. *Specify any "Blue Booking" requirements for inclusion in the National Geodetic Reference System.*

All of the above services must be performed under the direct control and supervision of a Land Surveyor licensed to practice in the Commonwealth of Virginia.

Owner's Responsibilities: The *specify organization name* shall provide or perform the following:

1. Access to and reproduction of all pertinent records maintained by the *specify organization name*.

2. General direction with regard to fundamental project objectives;

3. General review of all materials submitted;

4. Submit all completed permit applications;

5. Provide detailed inspection as appropriate.

Project Time: Required project time frames:

1. Preliminary Phase: *Specify exact or approximate time frames in days, weeks, months, and any associated relationships to specific tasks defined in this phase. Time frames should be specified for each deliverable (initial, draft, final) specified in this phase.*

2. Survey Phase: *Specify exact or approximate time frames in days, weeks, months, and any associated relationships to specific tasks defined in this phase. Time frames should be specified for each deliverable (initial, draft, final) specified in this phase.*

3. Final Report Phase: *Specify exact or approximate time frames in days, weeks, months, and any associated relationships to specific tasks defined in this phase. Time frames should be specified for each deliverable (Reference/Recovery Sheets, Project Control Schematic, Final Report) specified in this phase.*

Attachment: Location Map
Standards for GPS Surveying Services
Sample Reference and Recovery Data Sheet

Applicable GPS Standards

Specify Organization Name

Global Positioning Systems (GPS)
Standards for Surveying Services

1. GPS monument locations: Selection of GPS monument locations will address the following criteria:

   a. Geographic location and spacing
   b. GPS satellite horizon visibility
   c. Vehicular accessibility
   d. Occupation by GPS and other surveying equipment
   e. Permanency
   f. Ease of recovery
   g. Location within public rights-of-way, easements or properties
   h. Future use by *specify organization name* personnel, the surveying community and other interested parties.
   i. Potential conflicts with future development, including the construction of new residential areas, commercial centers and highways.
   j. Future use as identifiable control for future aerial photography.

   Whenever possible, existing vertical datum monuments should be utilized. If not available, new GPS control monuments will be located in a manner to provide, wherever possible, intervisability between adjacent control monuments for common azimuths.

2. New Monumentation: New GPS control monuments will be Poured-in-Place 8" diameter x 36" in length concrete/steel reinforced monuments w/standard *specify organization name* bench mark disks set in the top of the concrete posts. A magnet will be placed directly below the disk in the concrete post (See attached standard monument detail). Alternative monumentation may include the placement of the *specify organization name* bench mark disks in an accessible top surface of existing permanent stable structures (e.g. concrete bridge abutments, seawalls, etc.). the structure must be core drilled in order that the disk top is flush with the concrete surface. Additionally, the disk must be affixed in the structure with a high grade hydraulic cement.

3. Horizontal Accuracy Requirements: All GPS services must conform with FGCS (formerly FGCC) Geometric, Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques. (Version 5.0 dated May 11, 1983 and reprinted with corrections, dated August 1, 1989).

   Horizontal accuracy must comply with FGCS *specify order and class* --- as specified on the Geodetic Relative Positioning Accuracy Standards for Three-dimensional Surveys Using Space System Techniques table in the FGCS

Geometric, Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques.

4. Ties to Existing GPS Umbrella Network: All GPS monuments established under this contract must be properly tied to and constrained within the Virginia High Accuracy Reference Network (HARN). This network utilized published coordinates of NGRS first order stations *specify exact stations* and second order stations *specify exact stations*. Additionally, all GPS monuments established will be tied to and constrained with Phase 1, Phase II and subsequent Phase GPS monuments established for *specify organization name*, located within the GPS Umbrella Geodetic Network.

5. Preparation of Reference and Recovery Data: Reference/Recovery Data Sheets will be prepared on hard copy reproducible mylar and in *specify software/format* digital formats. A notice to users document (example attached) will be prepared that outlines the proper use of the geodetic data. A separate Reference/Recovery Data Sheet will be prepared for each GPS monument established and will denote the following:

   a. Virginia State Plane coordinates (NAD83) including date when the values were established (e.g. 1992)
   b. X & Y values in meters and U.S. survey feet
   c. Latitude and longitude
   d. Conversion angle
   e. Scale factor
   f. Reference and azimuth mark locations (including bearing, distance and elevation)
   g. National Geodetic Vertical Datum (1929) value in meters and feet. NAVD 1988 Datum is to be used when available
   h. Vertical Datum values in meters and feet
   i. Station name or number **

   ** *designation of the name or number will be coordinated with the specify organization name, department, division, etc., but the monuments are* ***not*** *to be stamped with the identifying station name.*

   j. Date and name of firm establishing the monument
   k. Applicable field book and page (establishing firm reference)
   l. Location sketch designating the monument location and pertinent field ties.

   (*provide and reference SAMPLE REFERENCE AND RECOVERY DATA SHEET*)

6. Final Report must be sealed, signed, and dated by the licensed Virginia land surveyor in responsible charge: This report should include the name of company and contact performing GPS services; equipment used for observations; software used for processing; methods used to obtain results; comparison of direction and distance results obtained for existing stations from observation and from published data; initial values in determining final coordinates.

Outline Format and Content for Vendor Responses

Vendors must submit proposals using the following format:

Section I: Firm Experience Record.

A. The number of years in private practice, and description of areas of general and specific expertise.

B. A list of similar completed projects, maximum of five (5), providing for each:

1. Location and description including size and complexity.
2. References.
3. Proposed team members who worked on the referenced projects and their specific assignments.

Section II: Project Management Approach.

A. A narrative statement of your understanding and perception of the project requirements and any unique features which you believe makes your firm the most qualified.

B. State when your firm can begin services.

Section III: Proposed Project Organization and Schedule

A. A project organization chart, indicating employee assignments and responsibilities.

B. Project schedule.

C. Resumes for each proposed professional employee, including:

1. Project responsibilities.
2. Education.
3. Background experience.

D. A list of secondary consultants, if any, (provide same detailed information as required for proposed professional employees) that could be used on this project.

E. *Organization name* uses *specify any required software*. Specify expertise in the use of *required software* and specify proposed uses and interfaces for this software in this project.

Notice to Users Example

Notice to Users Example (continued)

Notice to Users Example(continued)

Notice to Users Example(continued)

Notice to Users Example(continued)

Notice to Users Example(continued)

Notice to Users Example(continued)

Notice to Users Example(continued)

Appendix C

References

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